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Research article

Feeding efficiency of *Coccinella septempunctata* Linnaeus and *Propylea luteopustulata* (Mulsant) against Mustard aphid *Lipaphis erysimi* (Kaltenbach)

Sushila Bajracharya[1] | Prem B. Budha[1]* | Suraj Baral[2]

[1] Central Department of Zoology, Institute of Science and Technology, Tribhuvan University, Kathmandu Nepal
[2] Amrit Science Campus, Tribhuvan University, Lainchaur, Kathmandu, Nepal
*** Correspondence:** prem.budha@cdz.tu.edu.np

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Abstract

Ladybird beetles are efficient natural predators of aphids, particularly the widespread mustard pest, *Lipaphis erysimi*. This study compared the feeding efficiency of two adult predator ladybird beetle species *Coccinella septempunctata* and *Propylea luteopustulata* against *L. erysimi* in an experimental set-up for forty-nine days from 29 December 2019 to 15 February 2020. Five replicates of each beetle species were supplied with 100 aphids daily and their feeding rate was counted. Negative binomial regression analysis of these predator beetles showed that *C. septempunctata* consumed a significantly high number of mustard aphid individuals (29.42 ± 1.33) than *P. luteopustulata* (23.20 ± 1.07) at room temperature and relative humidity. Temperature and relative humidity also influenced the feeding rate of these beetles. The feeding rate of *P. luteopustulata* against a mustard pest aphid is described for the first time. The findings of the study will be an important aspect in the biological control of pests in Nepalese agroecosystems.

Keywords: Agroecosystems; Aphidophagy; Coccinellid; Ladybird beetle; Biological control

1 | Introduction

Mustard aphid *Lipaphis erysimi* (Kaltenbach, 1843) is one of the most destructive insect pests of cruciferous crops such as mustard and radish (Manpoong et al. 2017) causing a great loss (upto 97.6 percent) of mustard yield (Patel et al. 2004; Kumar et al. 2022). It feeds on plant sap affecting natural development and also acts as vector to transmit variety of plant viruses. Chemical insecticides are major management practice for mustard aphid control (Kafle & Jaishi 2020). Overall hidden and external costs of pesticides including regulatory costs, human health costs, environmental costs, and defensive expenditures reached the value of US$39.5 billion per year in the early 1990s (Bourguet & Guillemaud 2016). In Nepal, expenditure for pesticide import and formulation is more than 3.67 million USD (Dhital et al. 2015), and consumption of about 5163.61 USD (Adhikari 2018). Pesticide use is also linked to several acute and chronic health problems, more noticeable in developing countries including Nepal (Jørs et al. 2018). So, biological control of aphids is considered a better substitute against pesticides to restore natural balance with protection to the plants (Bellows 2001) and improved human health (De Clercq et al. 2011).

Aphid populations are targeted by a guild of natural enemies dominated by top predators like ladybird beetles, syrphid flies, and lacewings in agro-ecosystems (Polis et al. 1989). Amongst aphid predators, ladybird beetles of the coleopteran family Coccinellidae are the most abundant in *Brassica* agroecosystem (Koirala 2020), which are important natural control agents of aphids (Kumar et al. 2013). Ladybird beetles of both stages adults and larvae are efficient natural predators of *L. erysimi* (Singh & Singh 2013) and several attempts have been made to control aphids by using predaceous ladybird beetle species globally (Khan et al. 2009). Indeed, there are 822 cases of ladybird beetles used as classical and several augmentative biological controls which gave at least partial control of pests in different parts of the world (Rondoni et al. 2020).

The seven-spotted ladybird beetle *Coccinella septempunctata* Linnaeus, 1758 is a widely distributed predator of soft bodied insects comprising at least 83 aphid prey species and it is an efficient natural predator of *L. erysimi* in tropical regions (Omkar & Pervez 2002). It has been introduced as a classical biological control agent of aphids globally (Shand et al. 1966; Stiling & Cornelissen 2005; Rondoni et al. 2020). The prey range of the other lady-bird beetle species of the genus *Propylea* particularly *P. dissecta* (Mulsant), *P. japonica* (Thunberg) and *P. quatuordecimpunctata* Linnaeus were studied for biocontrol potential against aphids and whiteflies (Pervez & Omkar 2011). However, studies on feeding efficiency of *P. luteopustulata* (Mulsant, 1850) is lacking. Both the ladybird species *C. septempunctata* and *P. luteopustulata* are predators of numerous aphid species. The adult body size of former one is fairly large with the maximum body length reached upto 12. 7 mm but the later species is comparatively smaller (5 to 5.3 mm). The elytral patterns of both of these species are highly variables depending on the environmental conditions and availability of food resources. Evaluation of aphidophagous species in specific agronomic situations is needed to assess their biological control potential (Heimpel & Jervis 2005). The research of efficient and economical methods through mass rearing of natural predators in the laboratory is necessary for the increasing demand for biological control using insects (Sarwar & Saqib 2010). Coccinellid predation rates measured in the laboratory reflect a similar pattern of prey consumption to the field with various aphid species (Finlayson et al. 2010). Various studies have been conducted to determine the predatory efficiency of *C. septempunctata* and other aphidophagous coccinellids consuming aphid species (Mishra et al. 2011; Mishra et al. 2012; Kumar et al. 2013). The adults and grubs of *P. luteopustulata* have been found feeding on different aphid species viz. *Aphis craccivora*, *A. gossypii*, *Brevicoryne brassicae* (Pervez 2004; K.C. 2019), and *L. erysimi* (Khan et al. 2009) in economically important plants like *Triticum aestivum*, and *Brassica campestris* (Rahatullah et al. 2011). It is distributed in Pakistan (Hayat et al. 2017), Vietnam, Bhutan, Myanmar, Sri Lanka, China, and reported from different districts of Nepal (Canepari 1997; Thapa 2015). *P. luteopustulata* has been reported as an ecologically important predator of aphids in North India (Pervez et al. 2020) but the further studies are necessary to clarify biocontrol potential of *Propylea* (Pervez & Omkar 2011). The current information on the feeding efficiency of *P. luteopustulata* is not yet available. The efficiency of aphid consumption by these two natural predators (*C. septempunctata* and *P. luteopustulata*) was investigated to find biological control of aphids for the future implication of aphid control as an alternative biological pest control. We hypothesized that two ladybird beetle species have different consumption rates for the same mustard aphids and are influenced by temperature and humidity.

2 | Materials and methods

2.1 | Field surveys

Two species of predatory ladybird beetles of mustard aphids *L. erysimi* namely *C. septempunctata* and *P. luteopustulata* (Fig. 1) were collected from the mustard field of Tribhuvan University premises from 29 December 2019 to 15 February 2020 and brought to the laboratory. Their aphid consumption rate was examined at room temperature for forty-nine days. Collected beetles were starved for 24 hours of collection from the field to standardize their physiological status in order to induce the same level of hunger. Five replicates of each predator species were placed in each petri-dish of 8.5 cm diameter × 1 cm height. Moist blotting paper was placed at the bottom of each petri-dish to maintain humidity and replaced whenever required. In each experimental replicate, 100 live aphids of *L. erysimi* along with the fresh twigs and flowers of the host plants were placed manually where one individual of starved *C. septempunctata* or *P. luteopustulata* already existed for 24 hours (Banfield-Zanin & Leather 2016; Maharjan et al. 2018). Aphids were counted daily in each petri-dish every 24 hours to evaluate the consumption rate. The number of unconsumed aphids in each petri dish was noted and added daily with live aphids to maintain the total number of 100 aphids per day (Solangi et al. 2007; Prabhakar & Roy 2010). Temperature and relative humidity (RH) were recorded daily by using a digital thermo hygrometer during the aphid count.

2.2 | Data analysis

We modeled the consumption rate of the aphids as a function of the species as categorical factors and temperature and humidity as the continuous variables using a negative binomial distribution function (Table 1). Before using the negative binomial function, we tested the

Table 1. Environmental variables selected for the model building.

S.N.	Variable	Unit	Meaning of variable	Explanation for variable choice
1	Temperature	°C	Temperature measured once a day.	Temperature highly influence consumption of aphid (Schwarz & Frank 2019).
2	Relative Humidity	%	Relative humidity measured once a day	High air humidity promotes ladybird beetles survival (Reznik et al. 2022).
3	Aphid consumption rate		Number of aphids consumed estimated by counting remaining aphids after every 24 hours.	Consumption rate gives information about the behavior of concerned predators in relation to feeding (Mishra et al. 2012).

overdispersion parameter for the global model for Poisson distribution using package AER (Kleiber & Zeileis 2008) and found the dispersion parameter significantly higher than zero. Therefore, we chose the negative binomial distribution as an alternative for the Poisson model. The negative binomial model was run using package MASS (Venables & Ripley 2002) and the package MuMIN (Barton 2019) was used to select the most parsimonious models ($\Delta AIC_c<2$; (Anderson & Burnham 2002) using "dredge" function using the Akaike information criterion adjusted for small samples. Before the modeling exercise, a correlation matrix of the variables was prepared to exclude variables with $|r| > 0.7$ for building the models. The information collected from the experiment was coded tabulated in Microsoft Excel, and analyzed using R (R Core Team 2021).

Table 2. Negative Binomial models describing the consumption rate of ladybird beetle species using the species, temperature and humidity as candidate variables.

Model parameters	K	Loglink	AIC_c	ΔAIC_c
Species + Temperature + Humidity	4	-4026.73	8061.47	0.00
Species + Humidity	3	-4028.25	8062.558	1.00
Species	2	-4037.45	8078.93	17.38
Species + Temperature	3	-4037.38	8080.82	19.27
Humidity + Temperature	3	-4116.77	8239.59	178.04
Humidity	2	-4118.29	8240.53	179.06
Null	1	-4127.49	8256.99	195.44
Temperature	2	-4127.42	8258.87	197.32

3 | Results

Altogether 49000 individuals of mustard aphid *Lipaphis erysimi* were fed to two adult predatory ladybrid beetle species *Coccinella septempuntata* and *Propylea luteopustulata* with same number (24500 indivuduals) to each species respetively for 49 days from 29 December 2019 to 15 February 2020. The average feeding rate of *C. septempunctata* was found 29.42 percent with a range of 0 to 88 aphids per day whereas *P. luteopustulata* consumed an average 23.20 percent aphids per day ranging from 0 to 69 aphids daily.

The model comparison of feeding rates of ladybird beetle species *C. septempunctata* and *P. luteopustulata* suggested that the model with the inclusion of species, temperature and relative humidity explained the feeding rate of these two species (Table 2).

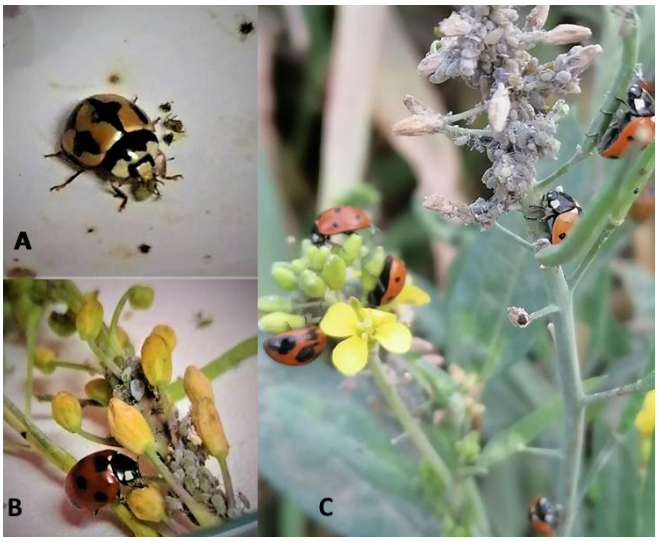

Figure 1. Predator ladybird beetles. A. *Propylea luteopustulata* feeding on aphid in lab, B-C. *Coccinella septempunctata* feeding on aphid in lab and in the field.

The most parsimonious model ($\Delta AIC_c=0$) suggested the feeding rates to be dependent on the species, temperature, and humidity (Table 2). Similarly, the model with the inclusion of species and the relative humidity ($\Delta AIC_c=1$) also has some support in explaining the consumption rates (Table 2). Other models did not have support to explain the consumption rates.

The model estimates showed that *C. septempunctata* had significantly higher consumption rates in comparison to *P. luteopustulata* (Table 3). Similarly, humidity had a slight but significant contribution to the consumption rate (Table 3). However, the model-averaged estimate of the two most parsimonious models did not present a significant contribution of temperature on the consumption rates of the two aphids in the experimentation (Table 3).

Table 3. Model parameter estimates for the consumption rate of aphids by two ladybird beetles *C. septempunctata* and *P. luteopustulata* using temperature and relative humidity. Estimates were averaged from the most parsimonious models ($\Delta AICc<2$).

	Estimate	LCL	UCL
Intercept	2.87	2.54	3.19
P. luteopustulata	-0.23	-0.27	-0.2
Humidity	0.006	0.003	0.009
Temperature	0.01	-0.002	0.03

4 | Discussion

The result showed that *C. septempunctata* had a higher efficiency in aphid consumption rate in comparison to *P. luteopustulata*. The former species has been studied as the important biological control agent against multiple pest prey species particularly aphids worldwide and has broad geographic success and ecological plasticity (Hodec & Michaud 2008). Many earlier studies have shown a higher consumption rate of *C. septempunctata* on aphids (Mishra et al. 2011, 2012; Maharjan et al. 2018). Prabhakar & Roy (2010) recorded the highest consumption by *C. septempunctata* (56±2.2) in laboratory conditions (24±20°C and 67±5% RH) when compared to *C. transversalis*, *C. sexmaculata*, *Micraspis discolor* and *Pullus pyrocheilus*. Devi et al. (2010) found that *C. septempunctata* had the highest feeding rate on the tea aphid *Toxoptera aurantii* along with other predators *viz. C. transversalis*, *Oenopia sexareata* and *Coelophora bissellata*. Maharjan et al. (2018) found feeding efficiency of larval stages of *C. septempunctata* and *Hippodamia variegata* and found former one as more effective biocontrol agent. The superior efficacy is largely attributed to differences in predator size between *C. septempunctata* and *P. luteopustulata.* The larger one has relatively high voracity and increased energy requirements than smaller ones (Mishra et al. 2011, 2012). It might also be due to the difference in prey preference between these two species where other *Propylea* species have less preference for *L. erysimi* as compared to other aphid species (Omkar & Mishra 2005) and *C. septempunctata* being comparatively efficient exploiter of *L. erysimi* as compared to other aphid species (Omkar & Srivastava 2003; Kumar et al. 2013). There is little information on the feeding ecology of small sized coccinellids particularly *Propylea* spp. Some available information on *P. dissecta, P. japonica* and *P. quatuordecimpunctata* suggests that despite of the smaller size they share prey species with other large coccinelids but has not wide range of prey items (Pervez & Omkar 2011). The feeding efficiency of *P. luteopulstuala* is given the first time with the feeding rate of 23.20 percent in comparison with *C. septempunctata* (29.42 percent). They share the same aphid prey items in the study area.

In this study, the temperature was found to have less effect as compared to humidity on feeding rate of aphid by ladybird beetles. Our study found that the total consumption of biomass by *C. septempunctata* was not affected by temperature. The low range of temperatures (only about 5°C) used in our study might be the cause of insignificance although earlier studies have found temperature to influence aphid consumption in general (Schwarz & Frank 2019). Also, consumption rates of ladybird beetle species are driven by the humid condition in the environment since a greater number of aphids should be consumed to meet dietary requirements under drought conditions (Banfield-Zanin & Leather 2016).

5 | Conclusions

Due to the comparatively higher aphid consumption rate of *C. septempunctata* it may play an important role as an efficient predator of the aphid pest *L. erysimi*. Despite the smaller size, *P. luteopustulata* is also found as an important natural enemy of *L. erysimi.* Relative humidity had a significant effect on the aphid consumption rate but not temperature. Both of these species are good natural predators that can be used in aphid control eco-friendly in the mustard field if commercially reared on the mass scale.

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Authors' contributions

Bajracharya, S. conducted the field, lab work and prepared the manuscript. Baral, S. analyzed the data. Budha, P. B. supervised the research and reviewed the manuscript.

Conflicts of interest

Authors declare no conflict of interest.

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